

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 May 2001 (03.05.2001)

PCT

(10) International Publication Number
WO 01/31867 A1

(51) International Patent Classification⁷: **H04L 25/06,**
25/02

(21) International Application Number: **PCT/EP99/08310**

(22) International Filing Date: 27 October 1999 (27.10.1999)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US): **NOKIA NETWORKS OY** [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **PIIRAINEN, Olli** [FI/FI]; Pikisaarentie 1 E 11, FIN-90100 Oulu (FI).

(74) Agents: **DRIVER, Virginia, Rozanne et al.**; Page White & Farrer, 54 Doughty Street, London WC1N 2LS (GB).

(81) Designated States (*national*): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

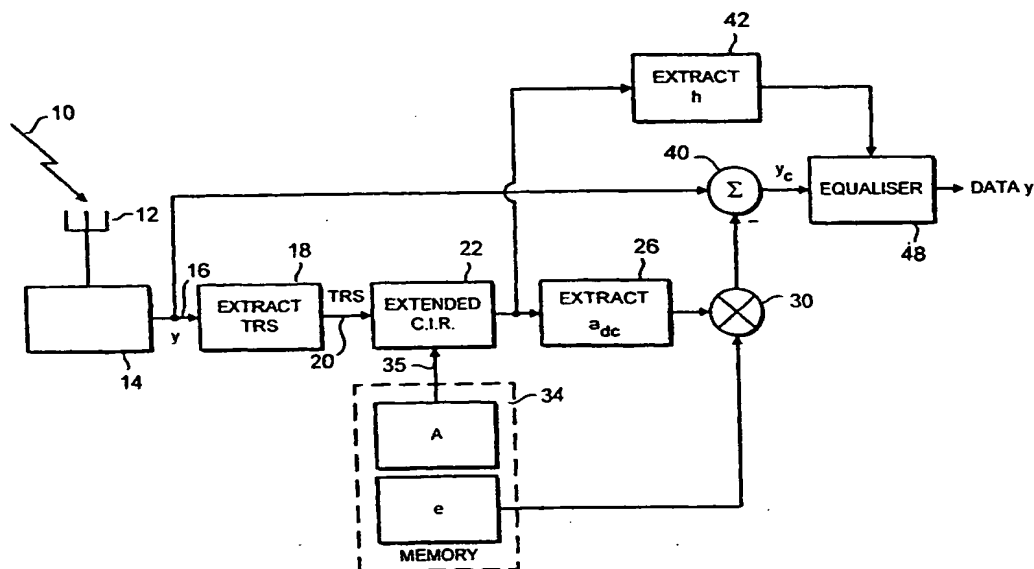
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— With international search report.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **DC OFFSET CORRECTION IN A MOBILE COMMUNICATION SYSTEM**



(57) Abstract: A method of simultaneously determining a DC offset and a channel impulse response from a received signal in a mobile communication system. The received signal Y comprising a set of training sequence bits that have been modulated prior to transmission. The modulated signals experience a certain phase shift and are rotated by a certain angle. The received signal may also comprise a DC offset component ADC that needs to be removed. By manipulation of the received signal samples with the knowledge of the original training sequence TRS and method of modulation used, it is possible to simultaneously estimate the communication channel's impulse response H and the DC offset ADC by finding the Least Square solution to a linear equation, such that the energy of the noise term introduced into the communication channel may be kept to a minimum.

WO 01/31867 A1

DC OFFSET CORRECTION IN A MOBILE COMMUNICATION SYSTEM

The present invention relates particularly to DC offset correction in a mobile communication system.

In a mobile communication system, signals are transmitted from mobile stations to a base station. A digital signal is prepared for transmission by the mobile station by subjecting it to a modulation technique and using the resulting signal to modulate a carrier wave at a certain frequency. In transmission of the signal from a mobile station to the base station, it may be subject to a number of different effects, depending on the environment through which the signal passes. That environment can vary considerably, depending, amongst other things, on the distance between the mobile station and the base station, and the interference caused by buildings and other structures in the area. It is quite common for a signal received from a mobile station at the base station to comprise a number of different multi-path effects and also to be subject to noise. Processing techniques at the receiver in the base station are known to resolve the effects of the environment through which the signal passes (communication channel) and also to take into account the effects of noise. The first step at the receiver is to sample the incoming signal to take a number of digital samples from the incoming analogue signal, normally sampled at the expected bit rate of the transmitted signal. This can give rise to a DC offset component which, if not removed, could corrupt the received signal samples such that the subsequent processing would be affected. In particular, the digital signal samples may be processed by an equaliser to compensate for the effects of the channel, and the known equalisers do not assume that a DC offset will be present. There are other sources that may introduce a DC offset and the magnitude of the DC offset may vary. It is an aim of the present invention to obtain a reliable estimate of the offset magnitude that needs to be removed from

the signal, without degrading the performance too much in the case that in fact no DC offset has been introduced.

In current base stations, a possible DC component is removed from the received signal by digital signal processing means. This is performed by removing the mean signal level from the real and imaginary component separately. Thus, the received signal y is considered to comprise both a real component and an imaginary component which are handled separately. A mean value (Ey) can be calculated over a whole burst to improve reliability. However, the transmitted data itself can cause the average value to have a false mean value, even in the case where there is no actual DC offset. This clearly degrades the performance of the subsequent digital signal processing.

According to one aspect of the present invention there is provided a method of simultaneously determining a DC offset (a_{dc}) and a channel impulse response (h) for a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising: generating a set of reference signal samples representing the training sequence bits and a set of rotation elements depending on the modulation applied to the digital data prior to transmission; receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset; and manipulating the received signal samples with the sets of received signal samples and rotation elements in such a way as to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function $F = |y - X \cdot h - e \cdot a_{dc}|^2$, where y represents the received signal samples, X represents the

training sequence samples and e represents the set of rotation elements.

According to another aspect of the invention there is provided a method of correcting for a DC offset in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising: receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset; manipulating the received signal samples with a set of reference signal samples representing the training sequence bits and a set of rotation elements depending on the modulation applied to the digital data prior to transmission to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function $F = |y - X \cdot h - e \cdot a_{dc}|^2$, where y represents the received signal samples, X represents the training sequence samples and e represents the set of rotation elements; and correcting the set of received signal samples in the digital data portion of the signal by removing the thus estimated DC offset from the received signal samples.

According to a further aspect of the invention there is provided a system for simultaneously determining a DC offset and a channel impulse response in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising: circuitry for receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset; a memory holding a set of reference signal samples representing the

training sequence bits and a set of rotation elements depending on the modulation applied to the digital data prior to transmission; an extended channel impulse response calculation unit for manipulating the received signal samples with the reference signal samples and the set of rotation elements in such a way as to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function

$F = \|y - X \cdot h - e \cdot a_{dc}\|^2$, where y represents the received signal samples, X represents the training sequence samples and e represents the set of rotation elements; and means for extracting the DC offset from the simultaneous estimate performed by the extended channel impulse response calculation unit.

A mathematically convenient way of manipulating the samples is to organise the received signal samples and the rotation elements as an extended training sequence matrix with $m+1$ columns, where m columns contain the reference signal samples and the $m+1^{th}$ column contains the rotation elements.

The precise manipulation of the received signal samples with the extended reference matrix is discussed in more detail in the following. The inventor has found that by using this extended matrix in a mathematical manipulation, which minimises the noise function w , an estimate can be made simultaneously of the channel impulse response and the DC offset, which can then be removed. For a matrix manipulation, an extended channel impulse vector is generated comprising m channel impulse response elements and a further element a_{dc} .

The invention is particularly but not exclusively applicable to a TDMA communication system, where each signal comprises a transmission burst.

The system described herein also includes an equaliser which uses the channel impulse elements extracted from the extended channel impulse vector to account for effects of the communication channel. It will readily be appreciated that after equalisation the data is subject to a number of subsequent processing steps in order to extract the original data in the burst. These are not described herein because they are known to a person skilled in the art and do not form part of the present invention.

For a better understanding of the present invention and to show how the same may be carried into effect, reference will now be made by way of example to the accompanying drawings in which:

Figure 1 is a diagram of a model of the transmission system;

Figure 2 is a further diagram of a model of the system;

Figure 3 is a diagram that represents the standard structure of a signal burst in a mobile communication system;

Figures 4a and 4b are diagrams that show the construction of the extended training sequence matrix and the extended impulse response vector, respectively;

Figure 5 is a block diagram of a receiver; and

Figure 6 is a flow diagram illustrating the method of the DC offset value removal.

Figure 1 is a diagram illustrating a model of a typical digital transmission system. It is shown together with an actual implementation of a cellular radio frequency (RF) communication system which is mapped to the model. The radio communication system comprises a base station BTS 2 and at least one mobile station MS 4 in communication with each other via a communication channel over an air interface. In the following description, the mobile station is considered to be the transmitter and the base transceiver station is considered to be the receiver. Reference numeral 6 denotes the transmission

signal being conveyed by the mobile station 4 to the base transceiver station 2. It will readily be appreciated however that the system and techniques described in the following are equally applicable where the base transceiver station 2 is acting as the transmitter and a mobile station MS 4 is acting as the receiver.

For the purposes of the following description, the transmitter is considered to comprise a modulator which applies the necessary modulation to the signal so that it can be transmitted over the communication channel. The communication channel itself can be modelled as a channel impulse response h and a noise component w that may be typically introduced as a result of some external perturbation to the system. The receiver side is considered to comprise a demodulator which carries out the necessary demodulation functions so that the originally transmitted information can be recovered from the received signal. Thus, according to the model of Figure 1 the modulator is considered as carrying out a modulation process and the demodulator is considered as carrying out a demodulation process. The assumption is made herein that it is necessary to apply a modulation to the signal prior to transmission, and thus to carry out an according demodulation process on receipt of the signal. In Figure 1, x is used to denote the signal prior to modulation and y is used to denote the recovered received signal after demodulation.

For the purpose of the present description, the modulation and demodulation process can be thought of as introducing two components. These components are a DC offset (a_{dc}) and a phase shift vector (e) which may be modelled as shown in Figure 2. That is, the received signal y differs from the channel-equalised version of the input signal x by a_{dc} and e . The magnitude of the DC offset (a_{dc}) is unknown and causes problems

with subsequent DSP techniques on the received signal if it is not removed. The phase shift vector (e) depends on the modulation method used, and thus is known. EDGE (Enhanced Data Rates for GSM Evolution) modulation is an example. For EDGE the selected modulation is $3\pi/8$ -8PSK. In the basic 8PSK constellation there are 8 equidistant points on the unit circle. This means that the transmitted symbols x_k can have eight possible values,

$x_k = e^{j \cdot i \cdot \pi/4}$, where i can have values from 0 to 7 depending on the symbol value (j is complex indicator).

Now for $3\pi/8$ -8PSK, the $3\pi/8$ shift means that the transmitted symbols are multiplied by a $3\pi/8$ rotating value. So,

$$x'_k = x_k * e^{j \cdot k \cdot 3\pi/8}, \text{ where } k \text{ is the symbol index.}$$

This means that in the receiver the transmitted samples (x'_k) must be derotated by $e^{-j \cdot k \cdot 3\pi/8}$ to get the original 8PSK constellation (x_k) to be equalised. This derotation will also make the DC offset rotate by $e^{-j \cdot k \cdot 3\pi/8}$.

Figure 3 illustrates a normal burst in a mobile communication system according to the GSM standard. This figure represents a burst received at a base station. For a TDMA system according to the GSM standard, mobile stations transmit bursts as modulated signals on respective carrier frequencies according to channels allocated to respective calls by a base station controller. One frequency channel may support up to eight calls, each call being associated with a respective burst, where each call is allocated a time slot in a TDMA frame in which to send the burst. Further details of a TDMA system according to the GSM standard are not described herein because they are known to a person skilled in the art. The normal burst contains two

packets of 58 bits (DATA) surrounding a training sequence (TRS) of 26 bits. Three tail bits (TS) are added to each end of the normal burst. The training sequence (TRS) is a predetermined sequence of bits which are sent by the mobile station (MS) and is known at the base station controller (BSC). It is normally utilised at the base station controller to estimate the impulse response of the channel over which the burst is sent. According to the system described in the following, it is used to jointly calculate the impulse response and the DC offset. The actual information which is transmitted is located in the data bits (DATA) of the burst.

Thus, the technique described in the following is based on the joint estimation of the channel impulse response and DC offset using the training sequence TRS. X is used in the following to denote the training sequence because as far as the model of Figure 1 is concerned, that is the input signal of interest for the following mathematical explanation. Before describing the system, an explanation of the mathematical techniques which are used in the system is set out.

The linear equation based on the models illustrated in Figures 1 and 2 is formally stated in **Equation 1**.

$$y = X \cdot h + e \cdot a_{dc} + w \quad \text{(Equation 1)}$$

Each digital sample of the signal is modulated prior to transmission and therefore experiences a phase shift depending on the modulation technique used. This phase shift is also known as rotation and may be represented as: $e^{-j\theta}$. Therefore a vector (e) may be formed which comprises the phase shifts of all the samples of the training sequence that are used as in **Equation 2**.

$$e = \begin{bmatrix} e^{-j.k.\theta} & e^{-j.(k-1).\theta} & \dots & e^{-j.(k-n+1).\theta} \end{bmatrix}^T \quad (\text{Equation 2})$$

where:

θ - represents the phase shift (and depends on the method of modulation that is implemented).

k - represents the time indexes (indices) of the samples taken of the training sequence.

n - represents the number of samples used in the training sequence.

For example, if GMSK modulation is used, the samples are all rotated by 90 degrees ($\theta = \pi/2$). Therefore, these samples will need to be derotated before the received signal is equalised.

Equation 4 can now be formulated by creating an extended training sequence matrix (X_e) and an extended impulse response vector (h_e) incorporating the phase shift vector (e) and the DC offset (a_{dc}) elements into the aforementioned matrix (X) and vector (h) as shown by **Equation 3**:

$$X_e = \begin{bmatrix} X & e \end{bmatrix} \text{ and } h_e = \begin{bmatrix} h \\ a_{dc} \end{bmatrix} \quad (\text{Equation 3})$$

$$y = X_e h_e + w \quad (\text{Equation 4})$$

Figure 4a illustrates the original training sequence and extended training sequence matrices. Figure 4b illustrates the

original impulse response and the extended impulse response vectors,

where:

m - represents the amount of impulse response taps
(i.e. $i = 0 \dots 4$)

n - represents the length of samples used for impulse
response estimation (i.e. $k = 26$).

Figure 4a illustrates that the matrix size is determined by the number of columns and rows that constitute the matrix. It is important to note that the original training sequence matrix (X) is composed of known elements. The number of columns m corresponds to the number of discrete taps that the proposed model of the impulse response filter will possess. The number of rows n is determined by the length of samples used from the training sequence for impulse response estimation. This makes the matrix size and the computational power required by the DSP flexible depending on the user's specification. The extended training sequence matrix (X_e) is created by adding an additional column of elements to the known training sequence matrix (X). This additional column contains the elements of the phase shift vector (e) (also known) and the size of the extended training sequence matrix is now $m+1$ columns by n rows.

Figure 4b shows the original and extended impulse response vectors (h/h_e). The extended impulse response vector has $m+1$ elements which means it can readily be manipulated with the $m+1$ columns provided by the extended training sequence matrix (X_e). The last element in the impulse response vector is the DC offset term (a_{dc}).

The extended impulse response vector \mathbf{h}_e can be found by ensuring that adequate estimates for the channel impulse response and DC offset can be made by minimising the function $F = |\mathbf{y} - \mathbf{X} \cdot \mathbf{h} - \mathbf{e} \cdot \mathbf{a}_{dc}|^2$, where F represents the Least Squares solution to minimise the noise (\mathbf{w}). Using the matrix format, **Equation 5** results.

$$\mathbf{h}_e = (\mathbf{X}_e^H \cdot \mathbf{X}_e)^{-1} \cdot \mathbf{X}_e^H \cdot \mathbf{y} \quad \text{(Equation 5)}$$

where; - \mathbf{y} represents the received signal, and
 - \mathbf{X}_e^H represents the complex conjugate transpose of the extended matrix.

Thus, this has effectively solved for the required number of channel impulse response elements and also for the DC offset term (\mathbf{a}_{dc}).

A block diagram for implementing the technique will now be illustrated in Figure 5.

It should be understood that the various blocks in Figure 5, although illustrated as separate interconnected entities, do not necessarily represent separate physical entities, but are intended to represent diagrammatically the various steps which are carried out. The blocks could be implemented as circuits or a suitably programmed microprocessor may effect each of the functions which is individually assigned to the blocks. Moreover, a receiver for a BTS or MS will have a number of components which are not illustrated in Figure 5 and which have been omitted for the sake of clarity and because they do not pertain to the present invention. An antenna 12 receives the transmitted signal 10 via the air interface from the mobile stations. The antenna 12 is connected to RF circuitry 14. The RF circuitry 14 operates on the received burst to downshift the

frequency to the baseband frequency and to sample the burst to provide from the analogue input signal digital sampled values. The output of RF circuitry 14 is denoted y and is a sampled burst comprising a plurality of signal samples y_i , sampled at the expected bit rate of the transmitted signal. As described above, Figure 3 illustrates the burst construction. The output of the RF circuitry 14 is supplied along line 16 to a TRS extractor 18 and also to a subtraction circuit 40 the purpose of which will be described later.

The training sequence TRS is extracted from the received signal y and supplied along line 20 to an extended channel impulse response unit 22. It will be appreciated that TRS is represented at this point as k ($k = 26$ in this embodiment) digital signal samples.

The extended channel impulse response unit 22 is used to calculate the so-called extended channel impulse response h_e which includes not only the "normal" channel impulse response taps $h(i)_{i=0...4}$, but also the required DC offset value a_{dc} . In known receivers, the channel impulse response unit uses the received training sequence TRS and calculates an estimated channel impulse response h by calculating the cross correlation between the received training sequence TRS and the known training sequence which is stored at the receiver, TRSref. In the present case, somewhat different calculations are performed according to the mathematical concepts described earlier. It will be appreciated that the extended CIR unit 22 comprises a suitably programmed processor for implementing the calculation. The extended channel impulse response unit 22 has access to a memory 34 in which there is prestored at least one so-called A matrix. The A matrix is calculated by manipulating the transpose of the complex conjugate of the extended training sequence matrix X_e^H as defined in Equation 6. The formation of the

extended training sequence matrix X_e has been described and is illustrated in figure 4a.

$$A = (X_e^H \cdot X_e)^{-1} \cdot X_e^H \quad (\text{Equation 6})$$

It will be readily understood that the diagrammatic layout of the memory 34 is for illustration purposes only and the use of the storage capacity can be in any appropriate manner. Moreover, a number of different A matrices can be precalculated and stored to take into account different phase shift vectors (e) and different training sequences. The extended CIR unit 22 can select the appropriate A matrix. The memory 34 also holds the phase shift vector (e) for a purpose which will be described later.

Therefore, the extended channel impulse response unit 22 has two inputs. One input is the training sequence TRS of the received signal and the other is the calculated A matrix. The extended CIR unit (22) calculates the extended channel impulse response vector h_e using Equation 5 (noting the value of A in Equation 6). The matrix manipulations (based on the Least Squares minimisation of the noise function F) allow the impulse response h and DC offset a_{dc} values to be solved by performing only one matrix multiplication, i.e. ($h_e = A \cdot y$).

A DC offset extract unit 26 extracts the DC offset a_{dc} from h_e and supplies it to a multiplier circuit (30). The other input to the multiplier circuit is the known phase shift vector e stored in a portion of memory. If the modulation method used resulted in no rotation of the samples, then this vector would comprise a set of ones. In either event, the phase shift vector (e) is multiplied with the DC offset (a_{dc}). The product $a_{dc} \cdot e$ is then subtracted from the received signal y at the subtraction circuit

(40). The output is a corrected signal y_c that is fed to an equaliser (48). The equaliser (48) also receives the normal channel impulse response h extracted from the extended channel impulse response vector h_e by an extract h circuit (42). The equaliser is known in the art and allows the data DATA y in the burst to be recovered.

In brief, the equaliser, as the name suggests, is a filter used to negate the effects of the communication channel (such as time dispersion, fading, etc.). The calculation of the impulse response vector allows an equalising filter to be constructed modelled on the inverse of the impulse response taps calculated and reflected in the elements of the first m rows of the matrix shown in Figure 4b.

Figure 6 is a flow diagram which describes the processing sequence as two parts. The first part (S1 to S3) can be done prior to receipt of a signal as part of a set up procedure. The second part is accomplished in the circuitry of figure 5. The first step S1 is to calculate the phase shift vector (e), based on the known modulation technique. Next, at S2, the extended training sequence matrix (X_e) is created. It is assumed that the training sequence matrix X is already known. The phase shift vector is added as a final column of this matrix resulting in the extended matrix ($X_e = [X \ e]$).

The final processing operation S3 performed in the set up phase is to calculate the new matrix A given by **Equation 6**. In operation, the extended CIR unit 5 receives two input signals. The first input S4a is the training sequence portion TRS of the received signal. The second input S4b is the A matrix. The extended impulse response vector (h_e) may be calculated at S5 from **Equation 5**, and contains an additional element over the

normal h taps, i.e. the DC offset (a_{dc}). Next at S6, the DC offset element a_{dc} is extracted from the extended CIR vector h_e . Finally at step S7, **Equation 7** is used to obtain the corrected signal that is sent to the equaliser circuit.

$$y_c = y - e \cdot a_{dc} \quad (\text{Equation 7})$$

This takes into account whether the samples have been derotated or not. If there is no derotation the e vector is a vector of ones. The correct signal is sent (step S8) to the equaliser after removal of the corresponding DC offset components.

It should be noted that Figure 1 and **Equation 1** are defined as a model of the transmission system and therefore it is assumed that a noise component (w) will be present. However, **Equation 5** is known as the LS (Least Squares) solution to a linear equation (i.e. **Equation 1**). This implies that the estimated parameters, h and a_{dc} are chosen so that the energy of the noise term (w) is kept to a minimum.

CLAIMS:

1. A method of simultaneously determining a DC offset (a_{dc}) and a channel impulse response (h) for a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising:

generating a set of reference signal samples representing the training sequence bits and a set of rotation elements depending on the modulation applied to the digital data prior to transmission;

receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset; and

manipulating the received signal samples with the sets of received signal samples and rotation elements in such a way as to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function $F = \|y - X \cdot h - e \cdot a_{dc}\|^2$, where y represents the received signal samples, X represents the training sequence samples and e represents the set of rotation elements.

2. A method of correcting for a DC offset in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising:

receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset;

manipulating the received signal samples with a set of reference signal samples representing the training sequence bits

and a set of rotation elements depending on the modulation applied to the digital data prior to transmission to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function $F = |y - X \cdot h - e \cdot a_{dc}|^2$, where y represents the received signal samples, X represents the training sequence samples and e represents the set of rotation elements; and

correcting the set of received signal samples in the digital data portion of the signal by removing the thus estimated DC offset from the received signal samples.

3. A method according to claim 1 or 2, wherein the set of reference signal samples representing the training sequence bits and the set of rotation elements depending on the modulation applied to the digital data prior to transmission are arranged as an extended training sequence matrix;

and wherein the manipulating step results in an extended channel impulse vector which comprises an estimate of the DC offset (a_{dc}) and a plurality of the channel impulse response elements (h).

4. A method according to claim 3, wherein the manipulation carried out with the extended reference matrix and the received signal samples to generate the extended channel impulse vector h_e is as follows:

$$h_e = (X_e^H \cdot X_e)^{-1} \cdot X_e^H \cdot y$$

where h_e represents the extended channel impulse vector, X_e represents the extended reference matrix, y represents the received signal samples and X_e^H represents the complex conjugate transpose of the extended reference matrix.

5. A method according to claim 3 or 4, comprising the additional step of extracting the channel impulse elements from the extended channel impulse vector and using the channel impulse elements in an equalisation step to remove from the received signal samples the effects of the communication channel for the signal.

6. A method according to any preceding claim wherein the signal comprises a transmission burst in a TDMA mobile communication system.

7. A method according to any preceding claim, wherein the received signal is sampled at the expected transmitted bit rate of the signal to produce a number of received signal samples corresponding to the number of bits of digital data and training sequence bits.

8. A system for simultaneously determining a DC offset and a channel impulse response in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising:

 circuitry for receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset;

 a memory holding a set of reference signal samples representing the training sequence bits and a set of rotation elements depending on the modulation applied to the digital data prior to transmission;

 an extended channel impulse response calculation unit for manipulating the received signal samples with the reference signal samples and the set of rotation elements in such a way as to simultaneously estimate the DC offset (a_{dc}) and the channel impulse response (h) by minimising the function $F = \|y - X \cdot h - e \cdot a_{dc}\|^2$,

where y represents the received signal samples, x represents the training sequence samples and e represents the set of rotation elements; and

means for extracting the DC offset from the simultaneous estimate performed by the extended channel impulse response calculation unit.

9. A system according to claim 8, which comprises circuitry for removing the DC offset from received signal samples representing the digital data portion of the signal.

10. A system according to claim 8 or 9, which comprises combining circuitry for combining the extracted DC offset with the set of rotation elements prior to removal of the DC offset from the received signal samples representing the digital data portion of the signal.

11. A system according to claim 8, 9 or 10, which comprises an equalisation circuit operable to remove from the received signal the effects of the communication channel for the signal using the channel impulse elements extracted from the simultaneous estimate performed by the extended channel impulse response calculation unit.

12. A method of determining a DC offset in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising:

generating an extended reference matrix having $m+1$ columns where m columns contain reference signal samples representing the training sequence bits and the $m+1$ column contains a set of rotation elements depending on the modulation applied to the digital data prior to transmission;

receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset; and

manipulating the received signal samples with the extended reference matrix to produce an extended channel impulse vector comprising m channel impulse elements representing the communication channel and a further element representing the DC offset.

13. A method of correcting for a DC offset in a signal received from a first station by a second station via a communication channel in a mobile communication system, the signal comprising digital data and a set of training sequence bits modulated prior to transmission, the method comprising:

receiving and sampling the signal to produce a plurality of received signal samples from the training sequence portion of the signal, the received signal samples possibly including a DC offset;

manipulating the received signal samples with an extended reference matrix having $m+1$ columns where m columns contain reference signal samples representing the training sequence bits and the $m+1$ column contains a set of rotation element depending on the modulation applied to the digital data prior to transmission to produce an extended channel impulse vector comprising m channel impulse elements representing the communication channel and a further element representing the DC offset;

extracting a DC offset from the extended channel impulse vector; and

correcting the set of received signal samples in the digital data portion of the signal by removing the thus determined DC offset.

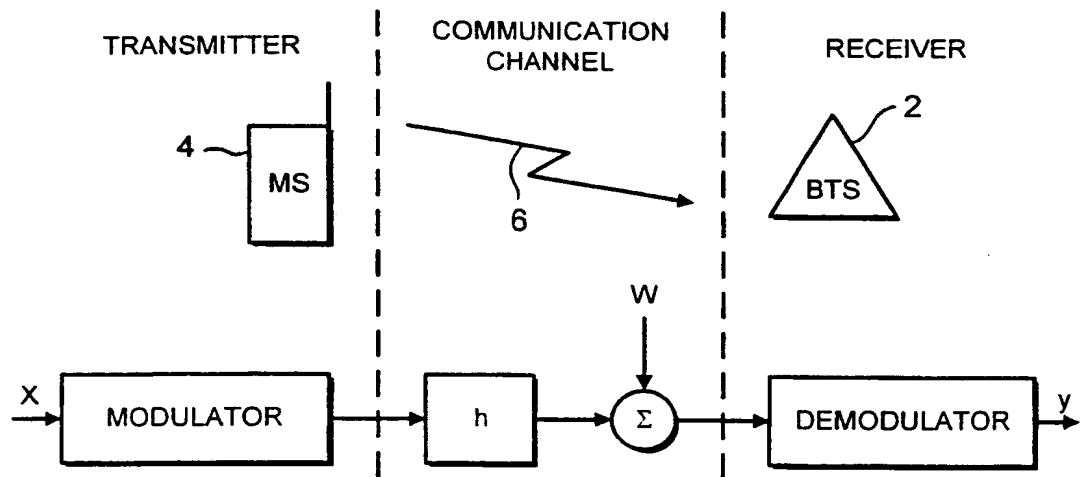


FIG. 1

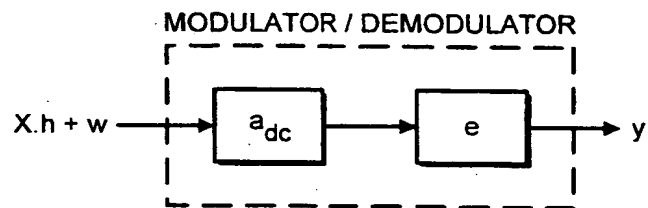


FIG. 2

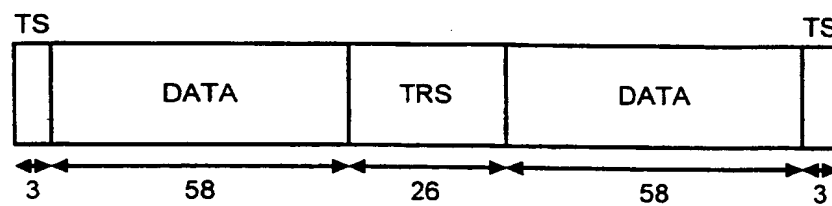


FIG. 3

2 / 4

$$\begin{array}{c}
 \text{m COLUMNS} \\
 x = \begin{bmatrix} x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1m} \\ x_{21} & \cdot & \cdot & \cdot & \cdot & x_{2m} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{n1} & \cdot & \cdot & \cdot & \cdot & x_{nm} \end{bmatrix} \\
 \text{n ROWS}
 \end{array}$$

$$\begin{array}{c}
 \text{m+1 COLUMNS} \\
 x_e = \begin{bmatrix} x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1m} & e_{1(m+1)} \\ x_{21} & \cdot & \cdot & \cdot & \cdot & \cdot & e_{2(m+1)} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{n1} & \cdot & \cdot & \cdot & \cdot & x_{nm} & e_{n(m+1)} \end{bmatrix} \\
 \text{n ROWS}
 \end{array}$$

FIG. 4a

$$\begin{array}{c}
 h = \begin{bmatrix} h_1 \\ h_2 \\ \cdot \\ \cdot \\ \cdot \\ h_m \end{bmatrix} \\
 \text{m ROWS}
 \end{array}
 \qquad
 \begin{array}{c}
 h_e = \begin{bmatrix} h_1 \\ h_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ h_m \\ a_{dc} \end{bmatrix} \\
 \text{m+1 ROWS}
 \end{array}$$

FIG. 4b

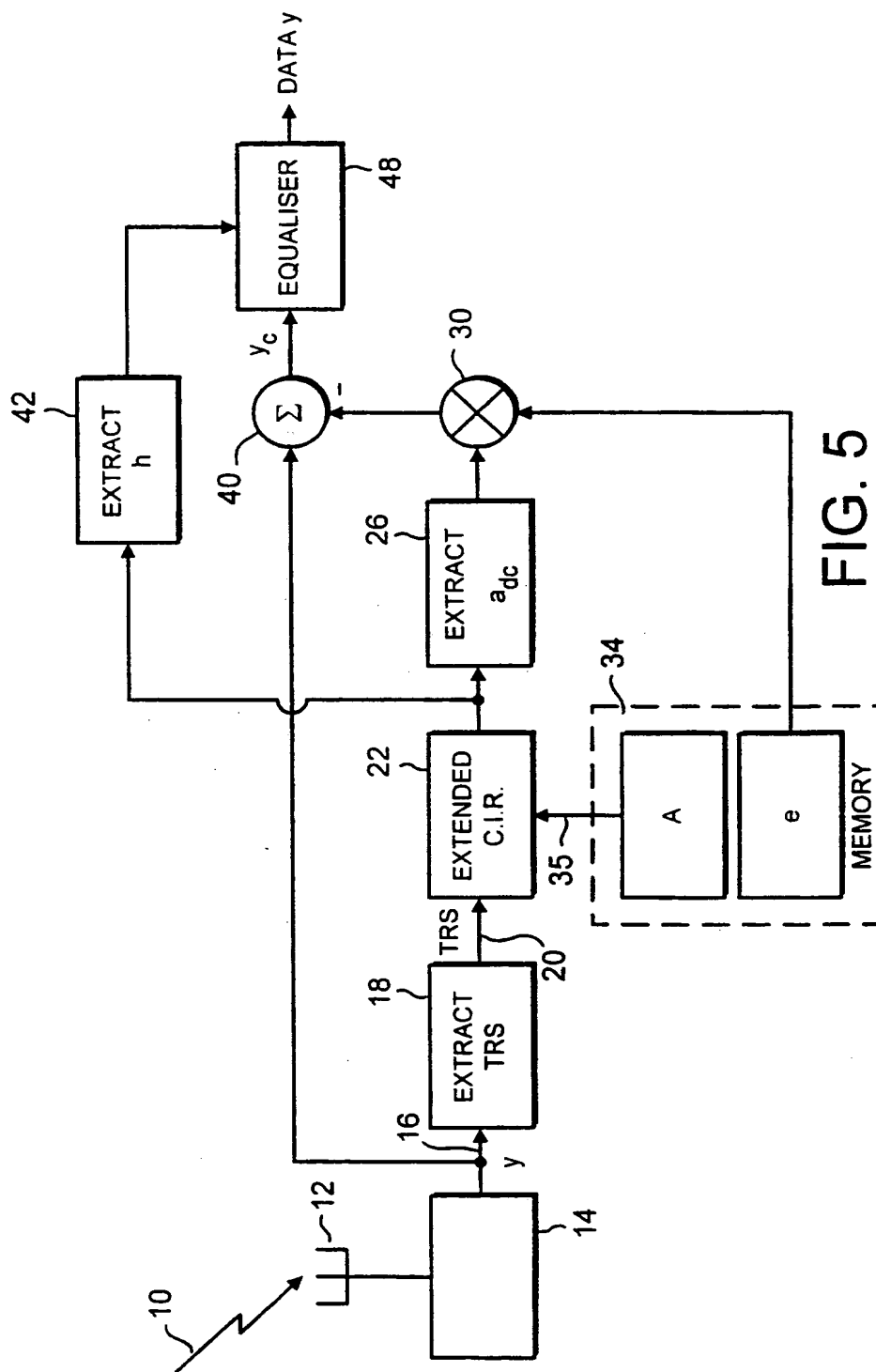
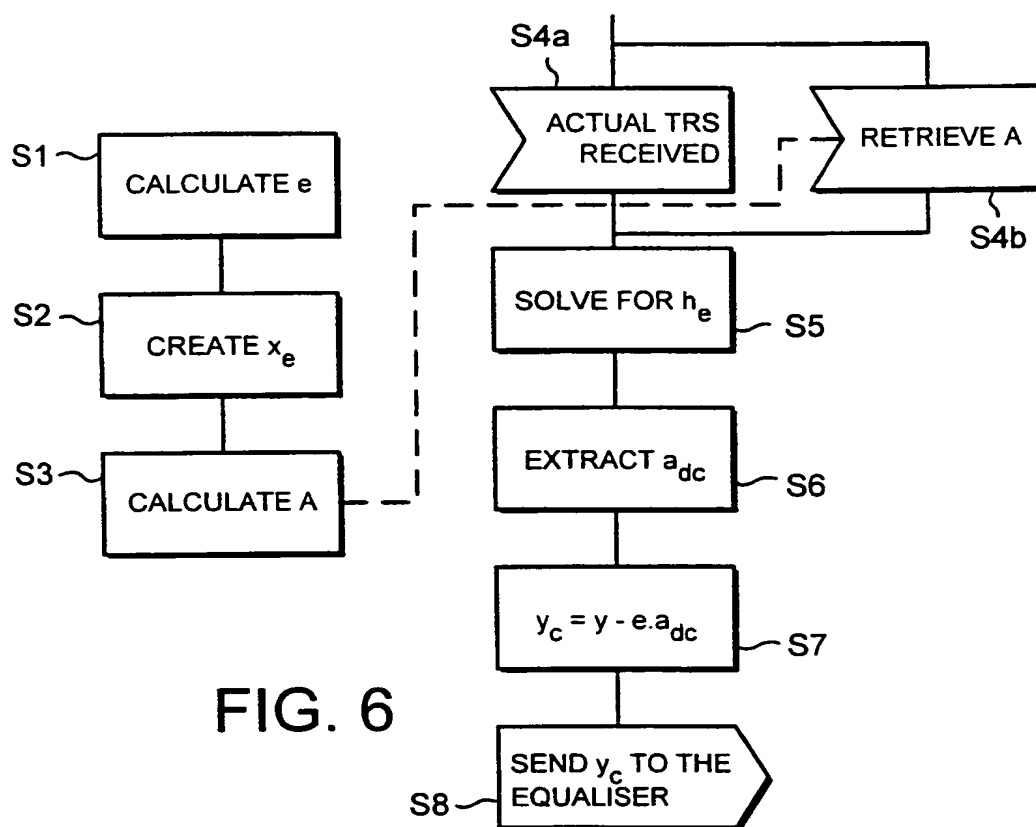


FIG. 5



INTERNATIONAL SEARCH REPORT

International Application No

PCT/EP 99/08310

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L25/06 H04L25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	DE 196 06 102 A (SIEMENS AG) 21 August 1997 (1997-08-21) abstract; figures 2,3 column 1, line 46 - last line column 2, line 12 -column 3, line 1 column 3, line 34 - line 54 column 5, line 24 - line 35; figure 1 column 5, line 63 -column 6, line 27 column 6, line 39 -column 7, line 6 --- -/--	1,2,6-11 3-5,12, 13

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

21 June 2000

Date of mailing of the international search report

30/06/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Sieben, S

INTERNATIONAL SEARCH REPORT

Inter national Application No

PCT/EP 99/08310

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>US 5 886 748 A (LEE MYEONG-HWAN) 23 March 1999 (1999-03-23) abstract; figures 1-5 column 2, line 56 - line 61 column 3, line 29 - line 65 column 6, line 63 -column 7, line 19 column 8, line 10 - line 32 column 8, line 62 -column 9, line 9</p>	<p>1,2,7-9, 11-13</p>
A	<p>WO 98 25351 A (NOKIA TELECOMMUNICATIONS OY ;PIIRAINEN OLLI (FI)) 11 June 1998 (1998-06-11) abstract; figures 3,4 page 3, line 13 - line 18 page 5, line 11 - line 25 page 6, line 11 -page 7, line 2</p>	<p>1-4,6-8, 10-13</p>

INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/EP 99/08310

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 19606102 A	21-08-1997	NONE	
US 5886748 A	23-03-1999	KR 165507 B CN 1158059 A DE 19652006 A GB 2309140 A, B JP 2851835 B JP 9214982 A	20-03-1999 27-08-1997 10-07-1997 16-07-1997 27-01-1999 15-08-1997
WO 9825351 A	11-06-1998	FI 964645 A AU 5054598 A CN 1209920 A EP 0885496 A NO 983344 A	22-05-1998 29-06-1998 03-03-1999 23-12-1998 18-09-1998